Inundation Modeling, Breach Parameters, and Consequences (Introduction)

Best Practices in Dam and Levee Safety Risk Analysis

Part C – Consequence Estimating

Last modified June 2017, presented July 2018

US Army Corps of Engineers®

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY FEDERAL ENERGY REGULATORY COMMISSION

TVA

Key Concepts

- Risk management involves consequence management
- Scalable approach based on goals of analysis
  - Initial characterization vs. prioritization vs. risk reduction
- Life risk is paramount
  - Understanding human factors is critical
- Build the case
  - How many people are exposed?
    - Warning and evacuation considerations
  - Flood characteristics?
    - Breach parameters
    - Inundation modeling
- Embrace uncertainty

Definitions

- Consequence
  - Direct vs. Indirect
- Life Loss
  - Population at risk
  - Exposed/threatened population
  - Fatality rate
- Economic
- Environmental
- Cultural

Essential Elements of Life Loss Estimate

- How many people are exposed to the flooding?
  - Initial distribution of people
  - Redistribution through evacuation
- How severe is the flooding?
- Are the people in a structure that can withstand the flooding?
- Will some of the people subjected to flooding die?

Empirical vs. Simulation Models

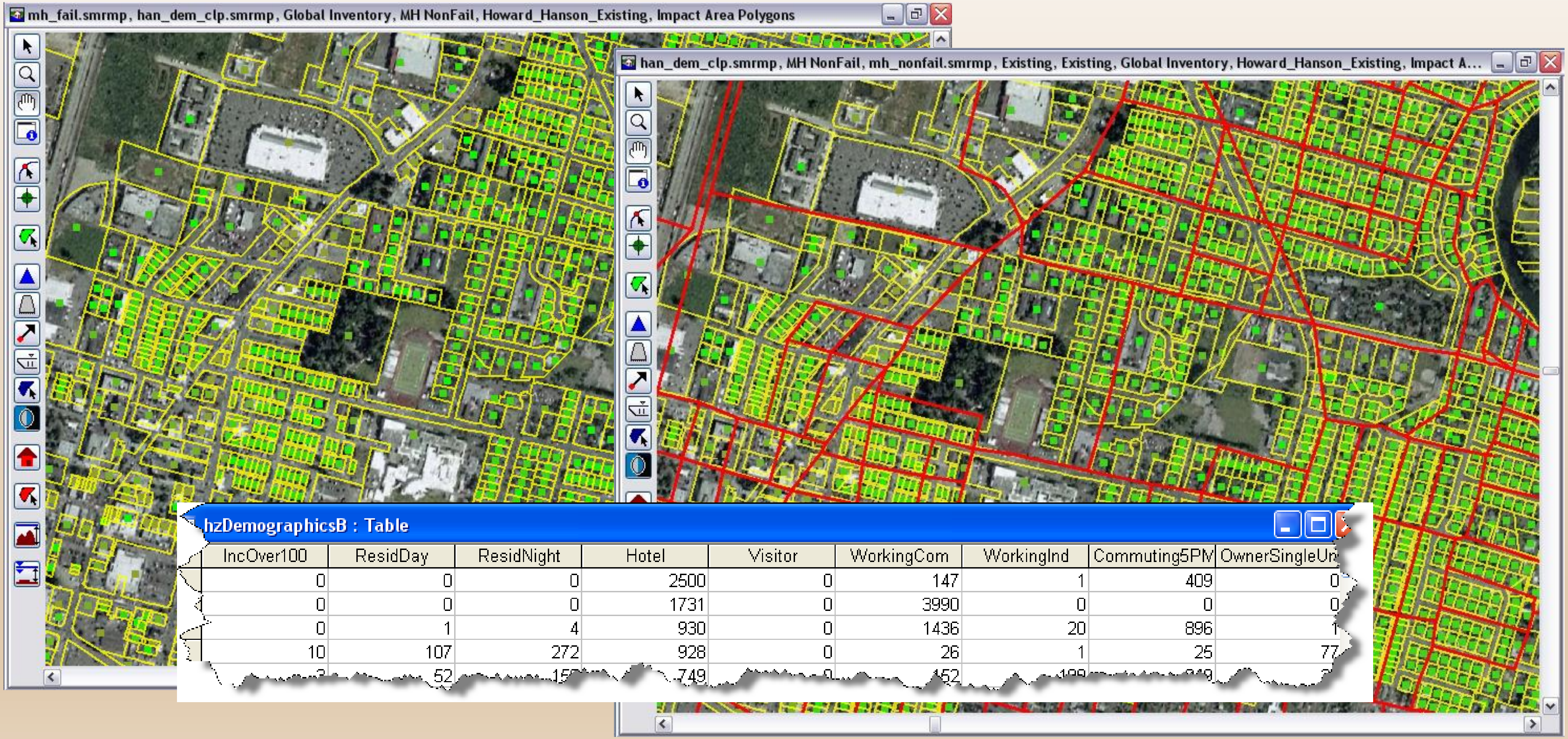
Empirical:

- Groups of PAR evaluated in aggregate
- Fatality rates ranges reflect evacuation rate assumptions – evacuation is not explicitly modeled
- Relevant parameters are warning time and the intensity of flooding

Simulation:

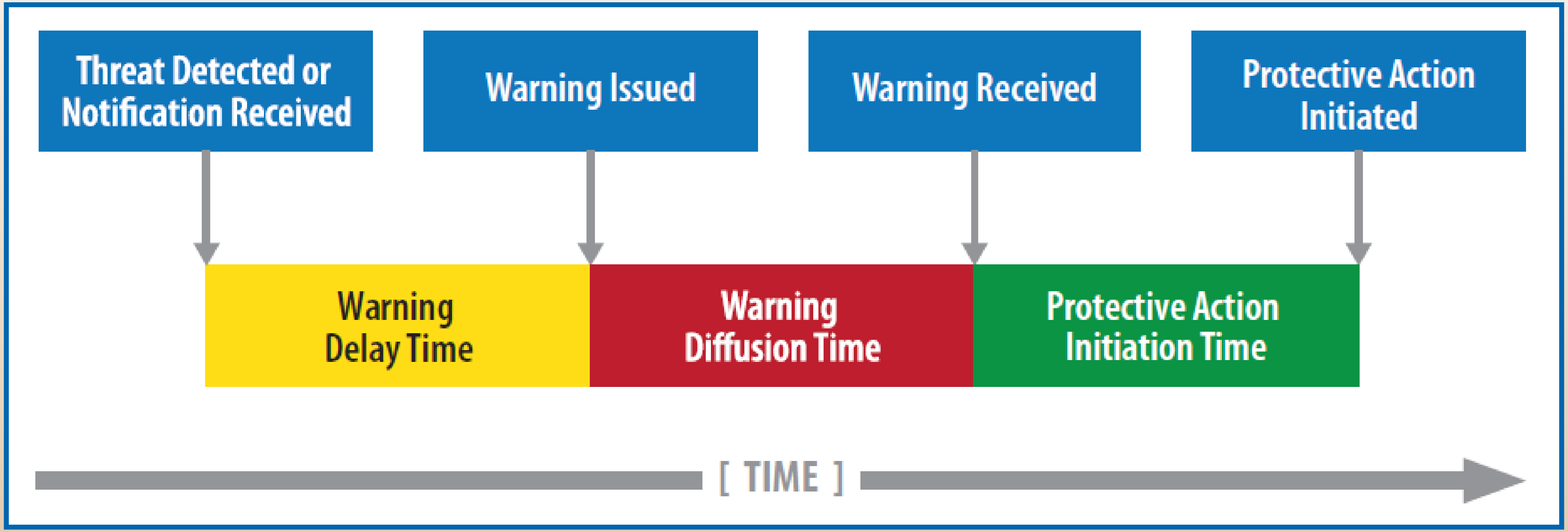
- Tracks movement of people and movement of water – evacuation is explicitly modeled
- Each individual or defined group is evaluated separately
- Fatality rates can be applied to PAR which exceed critical flood parameter thresholds

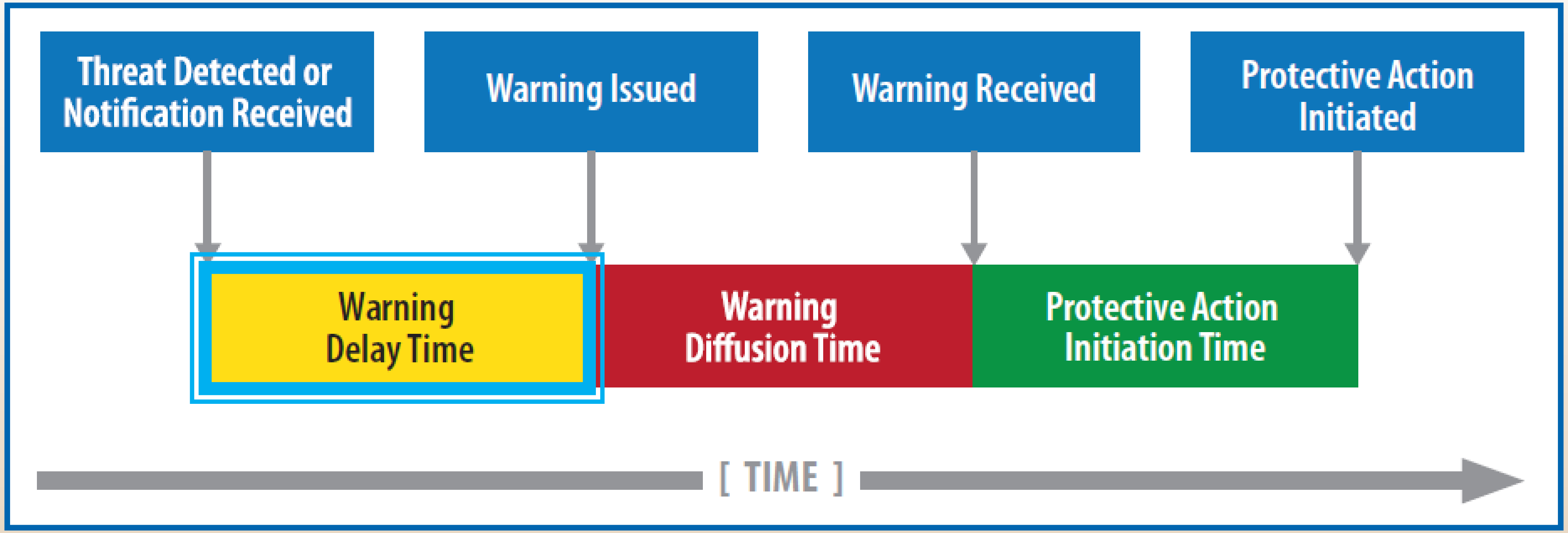
Initial Distribution of People



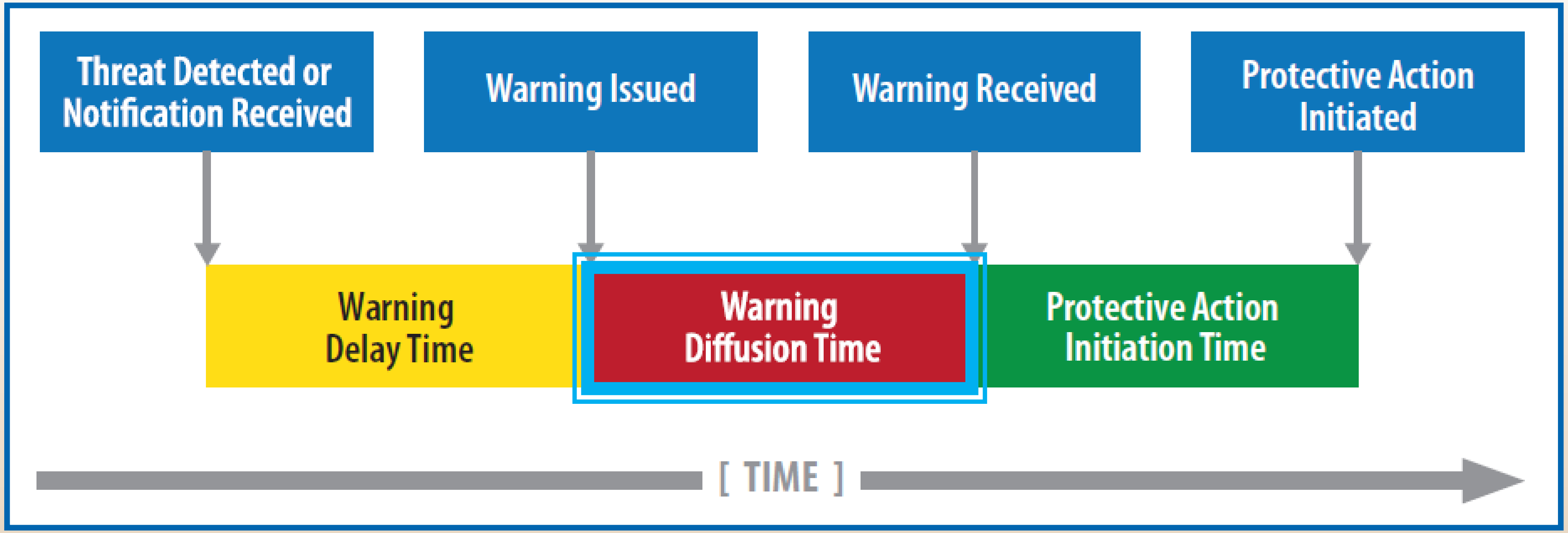
IncOver100	ResidDay	ResidNight	Hotel	Visitor	WorkingCom	WorkingInd	Commuting5PM	OwnerSingleUn
0	0	0	2500	0	147	1	409	0
0	0	0	1731	0	3990	0	0	0
0	1	4	930	0	1436	20	896	1
10	107	272	928	0	26	1	25	77

Redistribution of People (Evacuation Effectiveness)

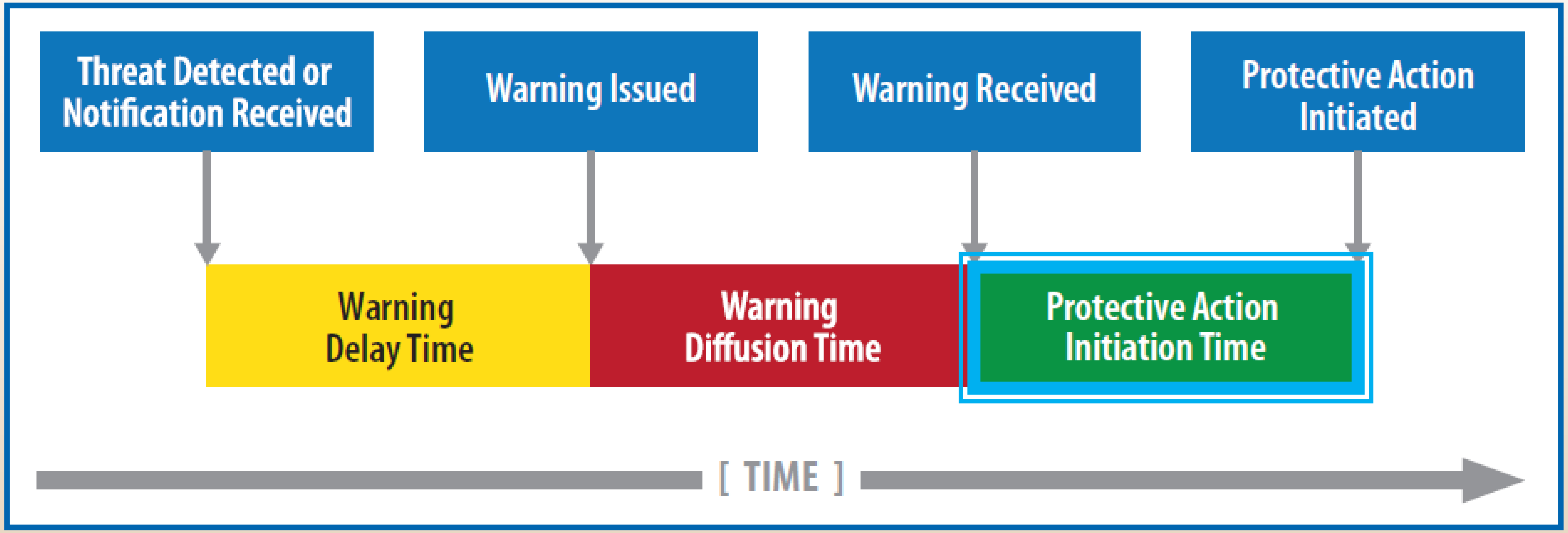




- Standard Warning Plan and Standard Operating Procedures are *Written Down*
- Warning Thresholds Are in Place
- SOP Drills Are Conducted
- Responsibilities are Identified and Clearly Define Authority To Issue Warnings



- Number and mix of warning channels
- Frequency of distribution
- Ability to wake people up
- Modern technologies



- Message content and style

Message Content

- **The single most important thing that an emergency manager can do** to motivate effective public protective action is to provide the best emergency messages possible.

SOURCE: say who the message

THREAT: describe the flooding

LOCATION: state the impact area

GUIDANCE/TIME: tell people

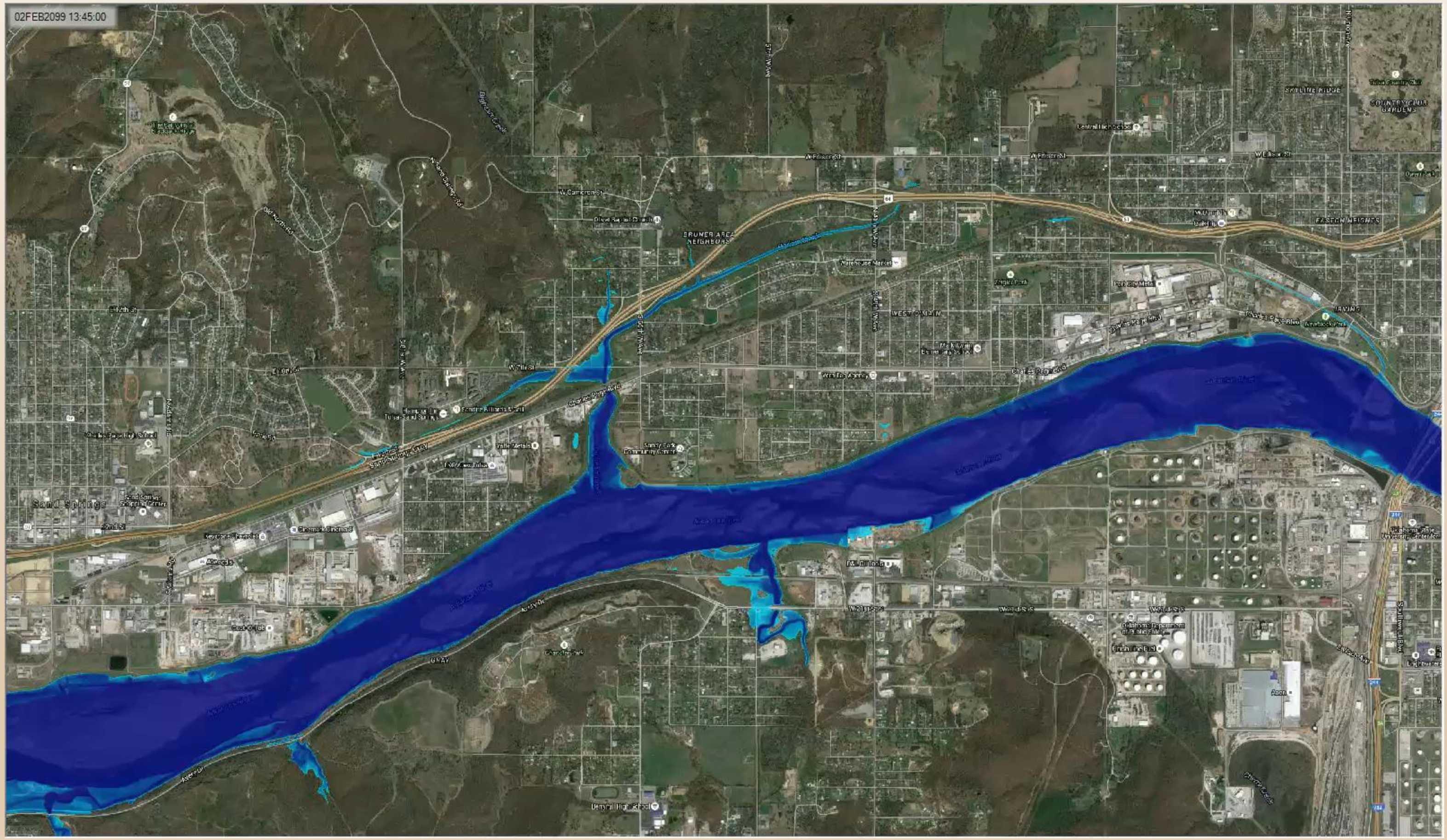
EXPIRATION TIME: tell people when the alert/warning expires and/or new information will be received

Essential Elements of Life Loss Estimate

- How many people are exposed to the flooding?
  - Initial distribution of people
  - Redistribution through evacuation
- How severe is the flooding?
- Are the people in a structure that can withstand the flooding?
- Will some of the people subjected to flooding die?

Flood Severity

- Depth
- Velocity
- Depth * Velocity
- Arrival time
- Extents



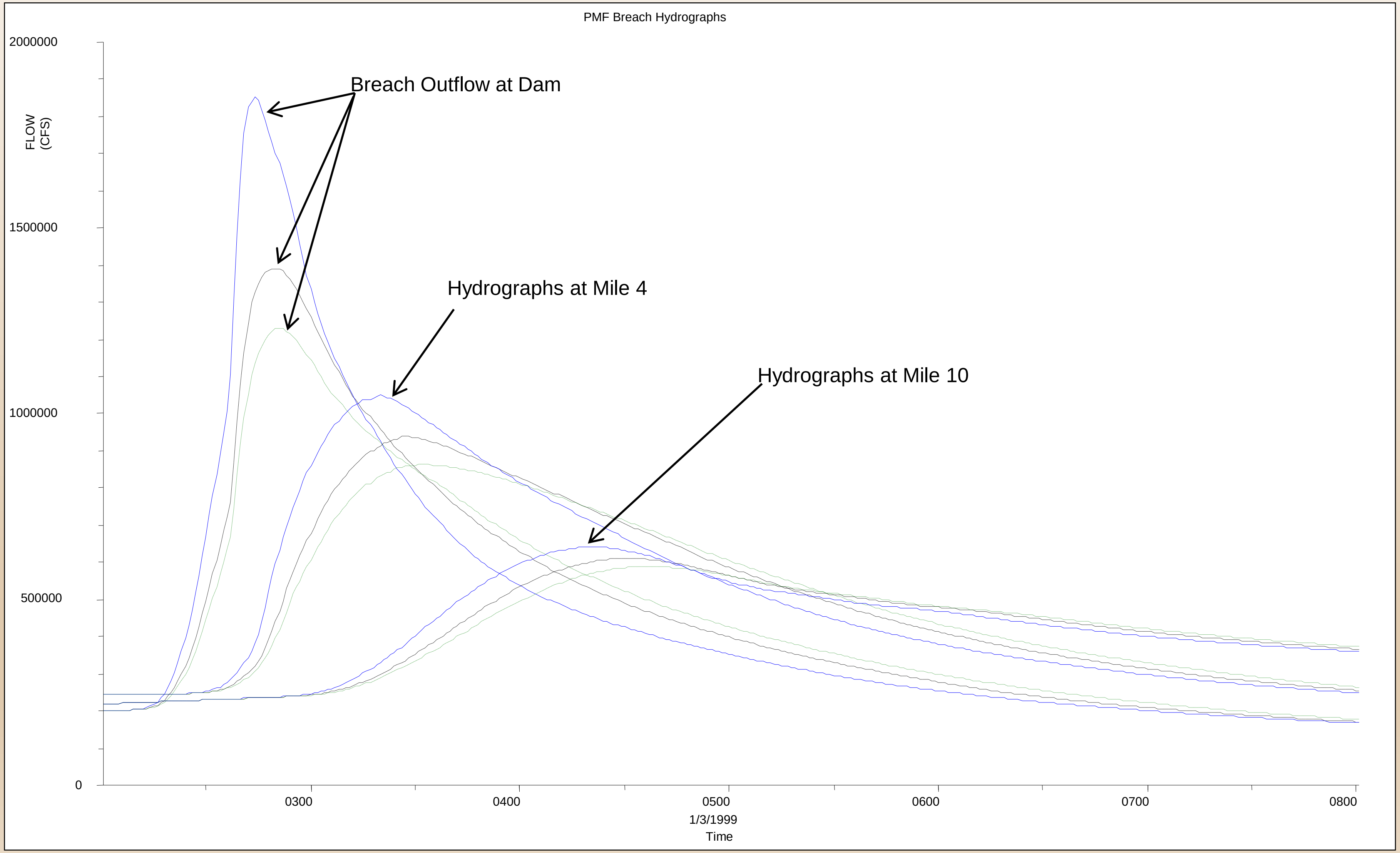
Key Concepts For Inundation Modeling

- Scenario
  - Pool or stage elevation and hydrology
  - Breach or Non-breach
  - Failure mode
- Breach parameters
- Terrain
  - 1d vs. 2d
- Initial conditions
- Incremental/coincident flows

Key Concepts for Understanding and Selecting Breach Parameters

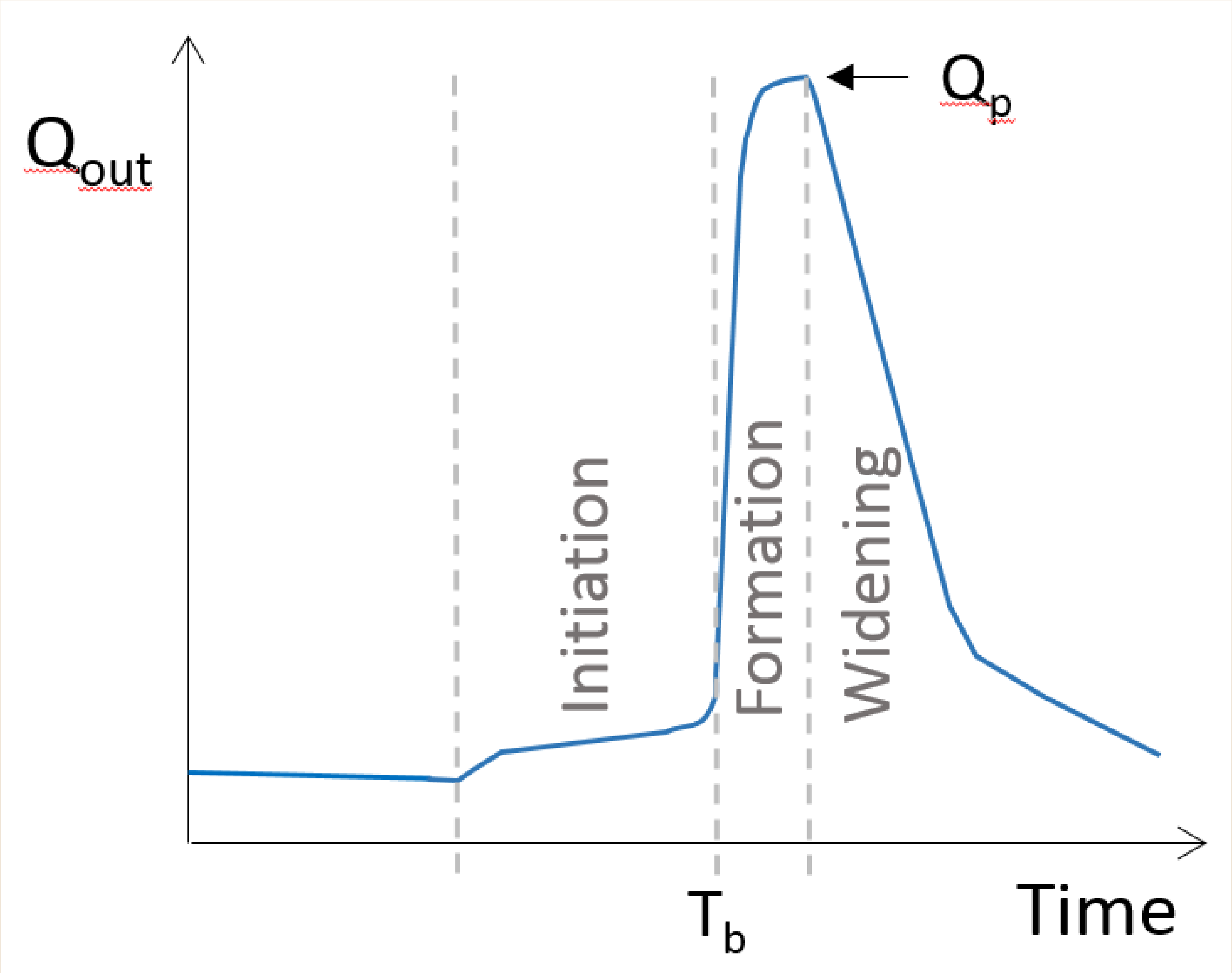
- Breach parameters can impact the following flood characteristics
  - Depth
  - Velocity
  - Arrival time (and therefore warning time)
  - Consequences
    - Life loss, direct damage, repair costs, etc
- Sensitivity analysis should be performed prior to detailed breach parameter analysis
  - Adopt scalable approach based on outcome
- Tradition empirical equations are based on dam breach cases

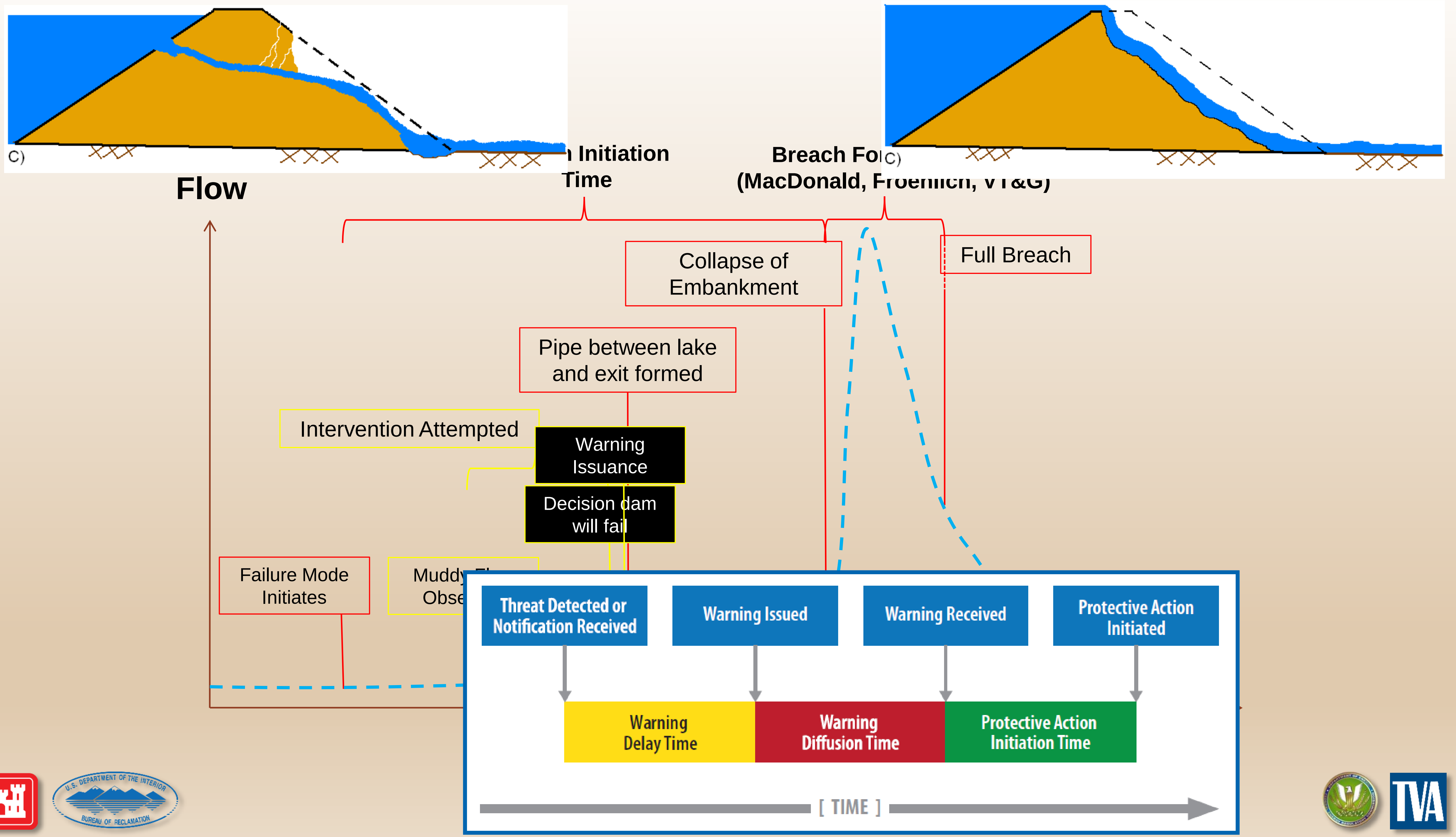
Does it Matter? Depends on downstream terrain, location of PAR and other factors..



Breach Parameters Definitions

- Breach initiation
  - Typically not included in hydraulic model
- Time of breach (T_b)
- Breach formation
- Breach widening





C)
Flow
Initiation
Time
Breach Fo
(MacDonald,
C)
Collapse of Embankment
Full Breach
Pipe between lake and exit formed
Intervention Attempted
Warning Issuance
Decision dam will fail
Failure Mode Initiates
Muddy
Obse
Threat Detected or Notification Received
Warning Issued
Warning Received
Protective Action Initiated
Warning Delay Time
Warning Diffusion Time
Protective Action Initiation Time
[TIME]

Options for Estimating Breach Parameters

- User defined
  - Historic data, empirical equations, site specific assumptions, etc
- Simplified physical breaching
  - Velocity vs. erosion rate
- Coupled embankment erosion and hydraulic model

Reference	Number of Case Studies	Relations Proposed (S.I. units, meters, m^3/s, hours)
Johnson and Illes (1976)		$0.5h_d \le B \le 3h_d$ for earthfill dams
Singh and Snorrason (1982, 1984)	20	$2h_d \le B \le 5h_d$ 0.15 m $\le d_{overtop} \le$ 0.61 m 0.25 hr $\le t_f \le$ 1.0 hr
MacDonald and Langridge-Monopolis (1984)	42	Earthfill dams: $V_{er} = 0.0261(V_{out} * h_w)^{0.769}$ [best-fit] $t_f = 0.0179(V_{er})^{0.364}$ [upper envelope] Non-earthfill dams: $V_{er} = 0.00348(V_{out} * h_w)^{0.852}$ [best fit]
FERC (1987)		B is normally 2-4 times h_d B can range from 1-5 times h_d Z = 0.25 to 1.0 [engineered, compacted dams] Z = 1 to 2 [non-engineered, slag or refuse dams] t_f = 0.1-1 hours [engineered, compacted earth dam] t_f = 0.1-0.5 hours [non-engineered, poorly compacted]
Froehlich (1987)	43	$\overline{B}^* = 0.47 K_o \left(S^*\right)^{0.25}$ K_o = 1.4 overtopping; 1.0 otherwise $Z = 0.75 K_c (h_w^*)^{1.57} (\overline{W}^*)^{0.73}$ K_c = 0.6 with corewall; 1.0 without a corewall $t_f^* = 79(S^*)^{0.47}$
Reclamation (1988)		$B = (3)h_w$ $t_f = (0.011)B$
Singh and Scarlatos (1988)	52	Breach geometry and time of failure tendencies B_{top} / B_{bottom} averages 1.29
Von Thun and Gillette (1990)	57	B, Z, t_f guidance (see discussion)
Dewey and Gillette (1993)	57	Breach initiation model; B, Z, t_f guidance
Froehlich (1995b)	63	$\overline{B} = 0.1803 K_o V_w^{0.32} h_b^{0.19}$ $t_f = 0.00254 V_w^{0.53} h_b^{(-0.90)}$ K_o= 1.4 for overtopping; 1.0 otherwise

Numeric Modeling Options for Estimating Breach Parameters

- User defined
  - Historic data, empirical equations, site specific assumptions, etc
- Simplified physical breaching
  - Velocity vs. erosion rate
- Coupled embankment erosion and hydraulic model

Process	WinDAM B/C	DL Breach	HR BREACH	NWS BREACH
River Hydraulics	No	N	N	N
Breach Flow	Yes	Y	Y	Y
Internal Hydraulic Routing	N	N	Y	N
Tailwater Submergence	Y	Y	Y	Y
Piping Initiated	Y	Y	Y	Y
Overtopping Initiated	Y	Y	Y	Y
River Erosion and Stability Failure Initiated	N	N	N	N
Headcut	Y	Y	Y	N
Breach Widening	Y	Y	Y	Y
Breach Deepening	Y	Y	Y	Y
Foundation Scouring	N	Y	N	N
Mass Wasting	Y	Y	Y	Y
Surface Erosion by Sediment Transport	N	Y	Y	Y
Sediment Volume	N	Y	Y	Y
Surface Protection Removal	Y	N	Y	Y
Composite Material Zones	N	Y	Y	Y

Essential Elements of Life Loss Estimate

- How many people are exposed to the flooding?
  - Initial distribution of people
  - Redistribution through evacuation
- How severe is the flooding?
- Are the people in a structure that can withstand the flooding?
- Will some of the people subjected to flooding die?

Building type	Partial damage	Total damage
Wood-framed		
unanchored	$v*d \geq 2\ m^2/s$	$v*d \geq 3\ m^2/s$
anchored	$v*d \geq 3\ m^2/s$	$v*d \geq 7\ m^2/s$
Masonry, concrete & brick	$v \geq 2$ m/s & $v*d \geq 3\ m^2/s$	$v \geq 2$ m/s & $v*d \geq 7\ m^2/s$

Essential Elements of Life Loss Estimate

- How many people are exposed to the flooding?
  - Initial distribution of people
  - Redistribution through evacuation
- How severe is the flooding?
- Are the people in a structure that can withstand the flooding?
- Will some of the people subjected to flooding die?

Ranges of fatality rates and life loss estimates are required for the empirical approach

Embrace Uncertainty